Insulating Biomaterials

N01-NS-9-2323

Second Quarterly Progress Report

January-March, 2000

Neural Prosthesis Program

National Institutes of Health

National Institute of Neurological

Disorders and Stroke

InnerSea Technology

Contributors:

David J. Edell, PI

Sean Sexton, Instrumentation and Software

Ying Ping Liu, Assembly and Testing

Karen K. Gleason, Chem Eng (MIT)

Hilton Lewis, Grad Student, Chem Eng (MIT-CVD Fluoropolymers)

Thomas B. Casserly, Grad Student, Chem Eng (MIT-HFCVD Silicones)

Shashi K. Murthy, Grad Student, Chem Eng (MIT-CVD Fluoro-silicones)

Long Term Soak Instrumentation

Temperature control systems for the high temperature soak systems were constructed and put in place this quarter to allow more accurate setting of the soak temperatures of the incubators and hot blocks used for the 384 channel electrometer system. In addition, two electrometer arrays were converted to lower sensitivity current to voltage converters because many of our more recent samples consisted of large surface area materials with proportionally larger leakage currents or polymer coatings that inherently flow more current per unit area. However, this limits the number of samples that can be accommodated at each temperature which may pose a problem in the future.

Clean Room

In order to test various cleaning and assembly procedures it is necessary to have a clean room environment for assembly. The ceiling of our class 1000 type clean room was sealed this quarter and entry-way closures were designed and ordered. Tacky mats, and clean room gowns and supplies and storage were also procured. A HEPA-filtered vacuum was purchased and used to clean all cabinets and supplies, tables, chairs, etc to begin establishment of a clean area. A class 100 type laminar flow hood with perforated stainless steel bench was also installed for the wire bonders. Local fume exhaust was installed to allow use of soldering irons, low toxicity solvents such as isopropyl alcohol, freon based cleaners and acetone.

Pull Test Station

Experiments to develop a better understanding of adhesion of various materials on various substrates were re-designed. The basic experiment is to affix a pull tab to a cleaned silicon dioxide surface using a variety of encapsulants and cleaning procedures, and then to peel off the encapsulant. Initially, Kapton tape was used as the pull tab, and “out of the box” wafers that had been in the lab for a considerable time were used as substrates. Silicones were used as the test encapsulants and substrates were either non-cleaned or cleaned in 2:1 concentrated sulphuric acid:concentrated hydrogen peroxide. The non-cleaned samples exhibited relatively low peel strengths while the cleaned samples exceeded the capacity of the pull test station, and eventually the material failed at the pull tab rather than on the adhered-to surface. Because of these limitations, a new peel test was designed. This test will embed fiberglass cloth in the encapsulant being tested. In addition to providing a strong pull tab that is integrated with the encapsulant, the embedded fiberglass also concentrates pull forces on a small cross-section of encapsulant. This will reduce the effect of material stretching which greatly influences the shape of the pull test curves.

New IDE Substrates

A tremendous amount of low power electronics technology is now available in the form of surface mount components. Much of this technology has been developed to serve the needs of military and consumer personal electronics. These components can be hand assembled into working, implantable circuits by “free-wiring” the devices in air, and then cleaning and embedding the circuits in various platinum catalyzed silicones. Such assemblies, while possible, are very difficult to achieve and expensive to reproduce. Use of solid substrates, with fine metal interconnects, can provide an efficient means of assembly. However, such assemblies may fail immersion in biological systems due to the potential for electrical conductance between traces on the surface of the substrate. Encapsulated, air assembled, chips are much less susceptible to failure resulting from formation of an unwanted conductive path because the cross sectional area between conductors is a minimum without the substrate. The presence of a substrate, however, provides a very large area cross section between all conductors. This is particularly acute when the traces are very small with very small spaces between them. In spite of these potential issues, use of an interconnect patterned substrate would allow much more rapid development of various circuits and systems being developed for implant applications. Accordingly, we have been developing a set of test structures

Because of the high value of being able to fabricate prototype systems using hybrid circuit substrates, interdigitated electrode arrays were designed for evaluation of possible encapsulants. An additional factor in the design of these substrates was the need for compatibility with soldering, solder paste, and wire bonding assembly techniques. All three assembly techniques can be used with various advantages for developing prototype devices. Substrate materials chosen were fused silica and alumina. Fused silica was attractive because substantial information now exists on the performance of silicones on properly cleaned silicon dioxide surfaces. However, fused silica is relatively fragile and expensive. Alumina is the standard high performance hybrid circuit substrate material. It is readily available and much less expensive than

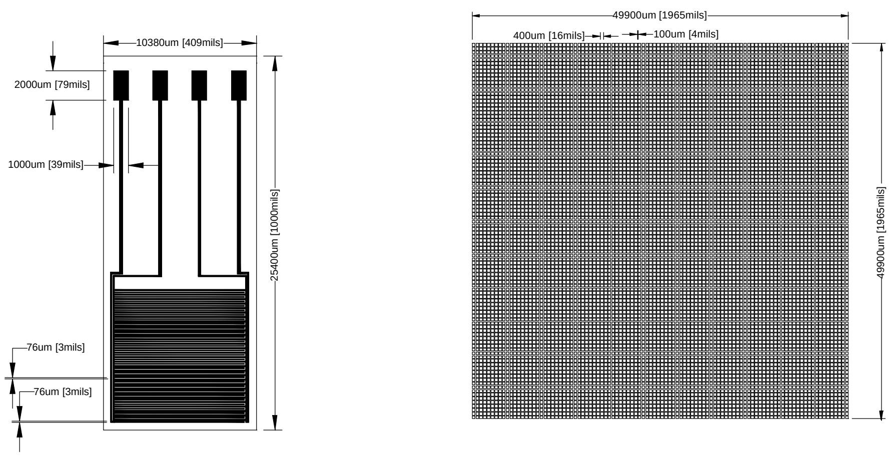

Figure 1: Hybrid circuit substrate test designs.

silica. However, little information exists on the performance of silicone encapsulants with alumina substrates. Both substrates were specified for interdigitated electrode arrays that could be used to evaluate insulation of the surfaces by encapsulants. The arrays were relatively large to generate a reasonable sensitivity to surface leakage currents constrained by 3 mil design rules. The overall layouts of the test circuits are shown in Figure 1.

New UM Substrate Designs

Designs for new University of Michigan technology test devices were developed in conjunction with Jamie Hetke of the Center for Neural Communication Technology. The purpose of these designs is to allow evaluation of thin film coating for the electrode areas of the neural probes, and to allow evaluation of a termination concept for a microwire based multi-conductor ribbon cable. InterDigitated Electrodes (IDEs) will be fabricated on the shafts of silicon microprobe arrays to determine surface conductivity under thin film coatings following intracortical implantation. Electrode capacitance characteristics will be used to determine the connectivity of these devices. Eight IDEs will be distributed on 4 shafts to sense local and distant variations in surface conductivity, and also in bulk resistivity of the insulating materials. The termination array for wire based multiconductor cables will be used to bond test devices to a defined pad area shared by wires bonded from a multiconductor cable. This may allow a more refined interconnection of prototype implantable microelectronics, particularly where the micro-ribbon passes through connective tissue and bone. Implantation of the “PassChip” described below is one example of an important need for this cable interconnect.

CMOS PassChip

The four layer circuit board for the optical pulse detector was designed and prototyped. A self-tuning detector circuit was included to optimize threshold settings based on pulse amplitudes. Self-tuning was valuable because the most noise free region of the pulses is on the rising edge at about 1/3 of the pulse amplitude. The adjusts the pulse detection threshold to be about 1/3 of the average pulse amplitude. This allows considerable variation in pulse intensity without loosing signals and with maintaining the detection threshold in the most noise free region of the waveforms. A circuit board layout will be designed next quarter for the photodetector.

Once the pulses have been reliably detected, the pulse intervals need to be de-multiplexed and the signals reconstructed. Initially, it was thought that a simple counter system could be used to digitally count the time between pulses, and then pass that information on to a computer in digital form. A prototype of this approach showed that the quantization noise for this approach was minimized by operating the counter at high speed. However, high speed operation of the counters results in wide data bytes which must be handled. While this approach is certainly feasible, it becomes relatively complex fairly quickly when dealing 14 data channels and the typical desktop personal computer. A second approach was to simply integrate the time between pulses using a constant current source and a capacitor that was reset after each pulse. Demultiplexing circuitry was used to steer the outputs to the appropriate channel. Output filtering was accomplished by use of a switched capacitor filter bank. A prototype of this circuit showed substantial issues with corruption of the signals by the digital aspects of much of the circuit.   Addition of improved sample and hold circuitry, and careful separation of the analog and digital pulse pathways resulted in great improvement of the output reconstructed signals. However, considerable excess noise remained. A four layer circuit board with careful attention to pulse, analog, and digital separation and impedance matching will be designed and tested next quarter.

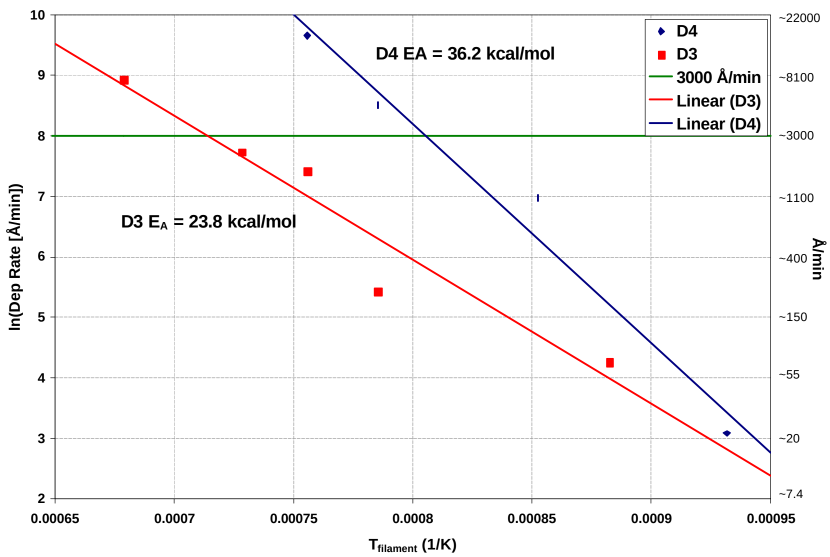

Figure 2: Arhenius plot for HFCVD growth from D3 and D4. At high filament temperatures, very high deposition rates (>3000 Å/min) can be achieved.

CVD Silicones and Fluorosilicones

Thomas Casserly began work on Hot-Filament CVD (HFCVD) silicone deposition. Reactor conditions resulting in HFCVD film growth were determined for two precursors, D_3 and D_4. Filament temperature was found to be the most important parameter for controlling the rate of film deposition. Figure 2 shows an Arhenius plot (ln growth rate vs. 1/Tfilament) for the two precursors. The regression provides the activation energy for the chemical reactions which are the rate limiting step for the HFCVD process. For both precursors, it is possible to achieve high growth rates (>3000 Å/min).

Fluorocarbon/Silicone Copolymers:

Both fluorocarbon and silicone CVD polymers have been investigated as biopassivation coatings. Fluorocarbon polymer coatings were found have very high resistivity, but could not be reliably made because of difficulties with pinholes and adhesion. Silicone coatings offered the additional advantages of excellent adhesion to silicon substrates (through covalent bond formation) and superior thermal stability. A hybrid fluorocarbon-organosilicon film would therefore have the potential to incorporate the desirable attributes of each class of material into a single coating. An important advantage of CVD is the ability to create copolymers easily as the synthesis of fluorocarbon-organosilicon copolymers by bulk or solution techniques is difficult.

PPCVD from the precursor F-D3 was investigated. The reactor conditions for film deposit were determined and approximately ten different films were grown. Fourier transform infrared spectroscopy (FTIR) analysis of the materials showed that the chemical structure of all the films was quite complex. Several peaks could not be easily identified. All films did have peaks assignable to large absorption in the hydroxyl and carbonyl regions. These types of polar bonding environments degrade dielectric properties. Simple soak test in water revealed that all of the deposited F-D3 films had poor adhesion as well.

Submitted paper to Chemistry of Materials summarizing pulsed plasma chemical vapor deposition (PPCVD) research performed during 1999 by Hilton Pryce Lewis (attached). This manuscript describes the structure/property/processing relationships for the PPCVD silicone films as well results obtained from long term soak test and lead wire coating experiments. (Not included on the posted version of the report.)